DALTON (J. C)

SPONTANEOUS GENERATION.

THE SUBSTANCE OF TWO LECTURES DELIVERED IN THE COLLEGE OF PHYSICIANS AND SURGEONS, NEW YORK, JANUARY 12TH AND 13TH.

Pres by the Author

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PROFESSOR OF PHYSIOLOGY.

[REPRINTED FROM THE N. Y. MEDICAL JOURNAL, FEB., 1872.]

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IT is the object of the present lectures to give the history of our knowledge on the subject of *Spontaneous Generation;* a topic which has been at various periods, and still is, one of the most mooted questions in general physiology. I do not propose to do this in an argumentative way, or with the object of proving conclusively its truth or falsity as a scientific doctrine; but rather to offer an account of the progress of opinion and discovery in this respect from the earliest periods, and the present condition of our knowledge on the subject, so far as definite conclusions have been reached.

Such a review of scientific questions is sometimes useful in many ways. It is often difficult to appreciate the real character or value of our present knowledge without recalling the successive steps by which it has been attained; and these steps have been in many instances so slow, and separated from each other by such long intervals of time, that the connection between them is easily forgotten. Nevertheless, the combined result has often been derived from many different discoveries, each of them quite as important in its time as those which are attracting attention now.

Beside, in the case of spontaneous generation, the nature of the question at issue has varied at different times, according to the general condition of knowledge in natural history, and the greater or less facility of observation derived from the invention and use of optical instruments.

The earliest scientific period to which we can refer is that of the natural history of the Greeks. At that time it seems to have been taken for granted that a large number of animals of various kinds were produced by spontaneous generation. This was not then considered, as it is now, in the light of an exceptional and almost experimental phenomenon; but as the regular and natural method by which a large class of organized beings made their appearance on the scene of animated existence. According to Aristotle, animals are divided, in respect to their mode of production, into two great classes. Some are produced by generation from parents, that is, from other animals of the same kind; so that there is, in these cases, a successive transmission of life from one to another, forming an unbroken series of parents and offspring. Life is transmitted, in animals of this class, by the production, either of living young, as in the *vivipara;* or by that of eggs, as in the *ovipara;* or by that of grubs and larvæ, as in many kinds of insects.

On the other hand, according to this view, some animals, as well as plants, are produced without having come from parents. They originate spontaneously, by the natural reunion and combination of ingredients analogous to their own; as, for example, in decomposing mud or slime, from the substance of vegetable tissues, or in the interior of other animals, from the excrementitious or superfluous material of their organs.

A large number of these spontaneous living products were thought to come directly from the earth itself. All the shell-fish, without exception, such as clams, oysters, rock-shells, cockles, limpets, etc., were said to be produced spontaneously in the slimy mud deposited from water, and to vary in kind according to the different characters of this deposit. Sea-nettles, sponges, and all similar productions, which have no shells, were said to be formed in the clefts of rocks in the same manner as shell-fish. Gnats and other small insects were known

to be produced, by metamorphosis, from slender aquatic worms; but these worms were understood to be formed spontaneously in the mud at the bottom of wells, or wherever there might be a collection of standing water with an earthy deposit at the bottom. The moth-grubs, so destructive to woollen textures, Aristotle taught, were produced spontaneously in the wool itself; wood-ticks came from the wood which they inhabited; and the little transparent book-louse, the insect found between the leaves of old books, originated in a similar way from the substance of the paper or parchment.

Even some of the fishes were regarded as having been produced, without parentage, from mud, from sandy loam, or from the floating scum on the surface of the water. Eels, certain mullets, a kind of atherina (aphya spuma), and some other small fish, are all enumerated[1] as originating in this way, by the direct combination and organization of inanimate materials contained in the mud of pools, or held in watery suspension. In the case of the mullets, one particular species only is described as being produced spontaneously; the others belonging to this family being known to reproduce their kind in the ordinary way. The fishes, as a class, therefore, were considered as presenting two different modes of reproduction; some of them being naturally produced from eggs, and others, as naturally, generated from mud or decomposing slime.

With our present knowledge on the subject of reproduction, we might be disposed to regard these statements as the offspring of either extraordinary ignorance or careless observation; and yet it would be a great mistake to do so. They were the best conclusions attainable at that time. Aristotle represented, in natural science, as in so many other departments, the entire scope and successful activity of the Grecian intellect. He occupied the position which was afterward held by the Buffons, the Linnæus, and the Cuviers of more modern periods; and it is certain that the opinions which he expressed must at least have seemed reasonable from his point of view.

It should be remembered, in the first place, that in all the cases now mentioned, whether among fish or other animals,

[1] Aristotle, History of Animals, Book VI., 15, 16.

the fact of spontaneous generation was never regarded as in any degree an accidental or abnormal occurrence; but always as the usual and regular mode of reproduction for those species. The belief in its existence was not due to any vulgar taste for the wonderful, or any tendency to run after extraordinary and supernatural phenomena; it was simply the result derived from an imperfect but fully scientific study of natural appearances.

Naturalists at that time investigated the reproduction of living beings as far as their means of observation would allow. They saw that some animals, such as sheep, horses, cattle, rabbits, and the like, produced living young similar to themselves. It was also plain that others, such as birds, reptiles, and many kinds of fish, produced their young by means of eggs. But *how* this generation took place in either case was entirely unknown. Naturalists were ignorant of the manner in which either the living young or the eggs were produced in the interior of the animal, and they knew nothing of the real relation between the two. For them, reproduction by eggs and reproduction by living young were two methods entirely distinct, having no resemblance to each other, and equally mysterious and incomprehensible in their nature. But they saw plainly that these two methods existed; and observation taught them that the young produced in both were directly traceable to parents of the same species.

On the other hand, there were certain kinds of animals, and these very numerous, in which no such connection between offspring and parents was perceptible. To all appearance, they were neither viviparous nor oviparous. They neither produced eggs or young themselves, nor were any parent animals of similar kind to be found in the same localities. There were worm-like larvæ which suddenly swarmed on the bottom of muddy pools; and fish, unlike any others in form and size, which were abundant at particular seasons, but contained neither ovaries nor eggs. There were maggots which appeared invariably at a certain period in putrefying meat, and others found enclosed in the centre of vegetable excrescences; beside various kinds of parasites inhabiting the cavi-

ties and even the solid organs of other animals. These creatures of doubtful origin showed themselves, for the most part, in moist and slimy deposits, containing a mixture of organic substances, and exposed to the action of the sun and air; or in some secret recess where organic material was already supplied, and where no access from without appeared to be possible. They were, therefore, supposed to be generated spontaneously from the materials on the spot, simply because no other source of production for them was visible. It was not altogether an unreasonable conclusion from the evidence then attainable; and, although mistaken in fact, it was reached by a direct course of scientific inquiry, exactly like that in use at the present day.

The mistake, as it existed, was due in great part to the inherent difficulty of the subject. For there is no point connected with the habits of animals surrounded by so many obstacles to a complete elucidation, as that of their reproduction. The secrecy of the animals in laying their eggs and in concealing the place where they are deposited; the sudden and unexpected manner in which ovulation and hatching are performed, the animal often coming from quite a different locality to deposit her eggs, and the young, on being hatched, at once dispersing to a still different one; the extreme variation in appearance, in many cases, between the parents and the young; the deposit of eggs in one season which are not to be hatched until the following spring, when the parents are all dead or have disappeared;[1] these and a multitude of other similar peculiarities often demand, in doubtful cases, an unusual exercise of skill and patience to learn the truth. Add to this the variety of metamorphoses to which many of the

[1] A remarkable instance of this is the case of the American seventeen year locust (*Cicada septendecim*), where a period of seventeen years elapses between the hatching of the larva and the appearance of the perfect insect; the larva all this time remaining buried in the ground, while the life of the insect in its perfect state does not last over six weeks. A brood of these locusts appeared in the city of New York and its immediate vicinity in 1843, and again in 1860. If they return with their accustomed regularity, their next appearance will be in 1877.

lower animals are subject before arriving at their adult condition, and the fact that in each successive stage the animal often inhabits a different locality, and sometimes even a different element, and the difficulty of tracing the connection in all cases between parents and offspring will be fully apparent.

This difficulty gradually diminished in process of time, as more knowledge was acquired in regard to the habits and growth of particular kinds of animals. In this way, by laborious research or fortunate observation, certain animals, previously supposed to originate spontaneously, were detected in their secret modes of reproduction, and were shown to be either oviparous or viviparous, like the rest. Fishes, which disappeared from their usual haunts to spawn elsewhere, were traced to their new hiding-places, and were then found to contain and produce eggs from which their young were hatched. There were other species in which the young differed so much in appearance from their parents that they had been regarded as independent and spontaneous productions; and, owing to their having no eggs or reproductive organs of their own, could not themselves, apparently, become parents. These animals were found to change in appearance, with the process of growth, so as to resemble at last the parent species; and, at the same time, to acquire reproductive organs, and become themselves capable of producing eggs. This knowledge, however, was necessarily acquired but slowly, and for one species of animal only at a time.

It was not until 1668, or more than nineteen hundred years after Aristotle, that Francis Redi, in Italy, discovered the true origin of the maggots in putrefying meat. Previous to that time the appearance of these creatures was one of the most undoubted instances of spontaneous generation. The invariable manner in which it occurred under the requisite conditions, the striking appearance of the maggots themselves, their visible size, their activity and voracity, and the great numbers in which they were produced, made the phenomenon appreciable by all, and one which could be easily brought under observation at any time. A piece of fresh meat, taken from a recently-killed animal, perfectly clean, and exposed in an open dish to the summer temperature, became in a few days,

as putrefaction commenced, the habitation of an abundant colony of little maggots. They rapidly increased in size and activity, and were soon evidently engaged in devouring the softened material; so that, when putrefaction had advanced to a certain stage, the dead flesh appeared almost to be converted into an animated mass of moving worms.

These worms, furthermore, were peculiar in their appearance and all alike. They always became developed in putrefying meat, and never in any other situation. The more rapid the putrefaction, the more rapidly they were produced. No similar creatures came from without; and the maggots themselves appeared first and only in dead and decomposing substances.

Redi's experiments on this point were very simple, but wholly conclusive. He noticed, while watching the production of maggots in different putrescible substances, that before the time of their appearance certain flies always hovered round the meat, and occasionally alighted upon it. He then suspected the maggots to be the progeny of these flies. In order to determine the point, he took, in the month of July, eight wide mouthed bottles and placed in them various pieces of dead flesh. Four of these bottles were left open to the atmosphere; while the remaining four were closed by pieces of paper carefully fastened over the mouth of each, and secured by a string round its neck. A short time afterward the flesh in the uncovered bottles was filled with maggots, the flies meanwhile passing in and out by the open mouth; but not a single maggot was visible in the closed bottles, even after several months had clapsed. The experimenter varied his method in several ways, but always with a similar result. He buried pieces of flesh, for example, in the ground, keeping them carefully covered for several weeks, and found that maggots were never generated under these circumstances; while they always made their appearance in meat to which the flies had access.

The conclusion, accordingly, was fully established. The maggots were not generated by the putrefying flesh, but by flies which were attracted by its odor, and deposited their eggs upon its surface. These eggs were hatched into mag-

gots, and the maggots were afterward developed into perfect insects similar to their parents—thus completing the round of ordinary oviparous generation.

It seems that the idea of putrefaction, or the decomposition of organic matters, as being especially favorable to the production of new forms of life, had always been a favorite one with the older naturalists. It occurs under many different forms in Aristotle, and is repeated by Pliny between three and four centuries afterward. The molecular actions, analogous to fermentation, going on in a decomposing material which had once been endowed with life, seemed not unlikely to breed new organizations of a different form. This notion evidently survived through the middle ages, since it is repeated by Fabricius in 1600, and by Harvey in 1650. It even forms the basis of the present doctrine of spontaneous generation, as it exists in our own day.

The experiments performed by Redi, therefore, by no means disproved altogether the fact of spontaneous generation, nor even its occurrence as a result of putrefaction. But it cleared up the obscurity surrounding the generation of insects produced from eggs and undergoing metamorphosis; and these species were, one after the other, withdrawn from the division of animals produced spontaneously, and transferred to that of the oviparous classes.

We now come to an epoch, however, which changed the aspect of the question very materially, and finally excluded from the field of spontaneous generation all the classes of animals formerly known to exist. This period is marked by the invention of the microscope and the discovery of the mammalian egg. This discovery, which showed that even viviparous animals really produce their young by means of eggs, took no less than one hundred and fifty years for its perfection. It was commenced by Regnier de Graaf in 1672, and was completed by Ernst von Baer in 1827. It demonstrated that reproduction takes place by means of eggs in quadrupeds and all the higher animals, as well as in birds, reptiles, fish, insects, and the like. The quadrupeds are merely distinguished, in this respect, by two peculiarities: First the egg, as formed internally in these animals, is of very small size, and needs

the use of the microscope for its recognition; and, secondly, it is developed into the young animal while still contained within the body of the parent. When finally produced, therefore, it appears as a young animal, and not as an egg. But it was no less an egg originally, and corresponds, in every important particular, with the egg in other classes of animals. Consequently, there is no essential difference, in the mode of reproduction, between oviparous and viviparous animals. They all produce eggs to begin with. But the ovipara lay their eggs while still undeveloped, and the young are hatched afterward; while the vivipara develop their young internally, and produce them completely formed.

Thus the three different methods of reproduction, formerly regarded as on an equal footing and quite distinct from each other, namely, that by living young, by eggs, and by spontaneous generation, no longer existed. Hereafter, the oviparous and viviparous animals were understood to be all essentially oviparous. The mechanism of the function, also, came to be better understood, with improved means of observation, and much of its mysterious and incomprehensible character gradually disappeared. There now remained but one kind of reproduction distinct in character from the rest; namely, that by spontaneous generation. This one continued as incomprehensible in its nature as before. But the number of species supposed to be generated in this way had been in the mean while rapidly diminished, and many of them had taken their places, as time went on, among those known to produce their young by means of eggs. In this way the fact of spontaneous generation lost its rank, as a great natural division of the reproductive function; and came to be regarded rather as an exceptional phenomenon, confined to a very few species, whose existence could not be accounted for in the ordinary way. Its territory was narrowed exactly in proportion as the knowledge of natural history advanced; and it became reduced almost exclusively to the class of animals known as *entozoa*, or internal parasites.

These are organisms which live within the bodies of other living animals.

There are many kinds of these entozoa. Some of them are found in the intestines, others in the liver, the kidneys, the lungs, or the heart and blood-vessels; others on the surface of the brain, and others even in the muscles and in the globe of the eye. There is hardly an animal which is not liable to be inhabited by one or more parasites in different parts of his body. Each particular kind of parasite is peculiar to the species of animal which he inhabits, and even to a particular part of his body, often to a particular part of one organ. The ascaris lumbricoides is found in the small intestine, the oxyuris vermicularis in the rectum, the trichocephalus dispar in the cæcum. There is one kind of distoma living in the lungs of the green frog, another in those of the brown frog. The cysticercus cellulosæ is found in the cellular tissue, the trichina spiralis in the substance of the muscles. As a rule, they are not to be found except in these situations; and if they were, it is not easy to see how they could have effected an entrance, at least into the blood-vessels and the solid organs.

But the parasites, like all other animals, were at last found to come from eggs, and to reproduce their species by sexual generation. They exist only in certain organs of the living body, not because they are generated there from the animal fluids, but because it is only there that they can find the necessary conditions of their development, and the kind of nourishment that is suited for them. This is the secret of their being found in certain places and not in others. In nearly all, if not in all cases, their residence in the body of the larger animal is merely temporary, and continues only during a certain period of their growth. Both before and after that period they live in other situations; but at the time of changing their habitation, they also change their form, so that they could not be recognized as the same animal, unless carefully watched and followed through the different stages of their growth.

The proof of this is now complete, and the manner in which it has been reached forms one of the most remarkable chapters in the history of physiology. For human parasites, the class which presented the greatest difficulty in accounting for their origin may be represented by the two kinds known as

Cysticercus cellulosæ and *Trichina spiralis*. This difficulty consisted in the two following peculiarities: First, that the animals live enclosed in a distinct cyst, in the substance of solid tissues; and, secondly, that they are apparently sexless, and unprovided with generative organs. It was from 1850 to 1858 that the natural history of several kinds of cysticercus was established by the researches of Siebold, Küchenmeister, Van Beneden, and others. These parasites consist of a globular envelope, containing an involuted bag, at the bottom of which is a minute head, with four suckers and a crown of hooks, similar to those of certain varieties of *Tænia*. Experiments performed by feeding different animals with cysticerci, which resulted in the production of tænia, and by feeding others with the eggs of tænia, which in turn gave origin to cysticerci, convinced the experimenters that there was a physiological identity between the two forms, and that cysticercus was simply the imperfectly-developed embryo of tænia. This conclusion is now universally accepted. The mature articulation of a tænia, containing an abundance of fecundated eggs and embryos, is thrown off in the intestine of the animal inhabited by the parasite. After being discharged, it retains its vitality, under favorable conditions, long enough to migrate and attach itself to substances, which are swallowed as food by another animal. In the stomach and intestine of this second animal the tænia-articulation is digested and its embryos set free. They then penetrate the intestinal walls by means of the six calcareous spines with which they are provided, and thus reach other organs and sometimes distant parts of the body. Arrived at the cellular tissue, they become encysted, pass through the first stage of their development, and acquire the four suckers and double crown of hooks characteristic of the species. Here their development stops, and they remain quiescent until the animal which they inhabit is devoured by another, of the kind in which the tape-worm was originally domiciled. In this new situation their development is completed. The articulations of the tænia are produced and multiplied by successive growth, acquire sexual organs, and at last become filled with mature eggs, to repeat, as before, the process of reproduction. Thus the fact that the

cysticercus lives in the cellular tissue of one animal, and the tænia in the intestine of another, is like the fact, familiar to all, that the larva of the mosquito lives in the water, and the mosquito itself in the air. Both stages of existence are equally essential to the life of the animal: only, during the first stage the creature is embryonic and sexless; during the second it is fully developed and capable of generation. Similar discoveries, made a few years later, principally by Leuckart,[1] in regard to Trichina spiralis, showed that the encysted condition of this parasite is also a temporary one; that it is th progeny of a fully-developed, viviparous, intestinal worm; and that, when itself introduced into the intestine of another animal, it goes through a similar process of growth, and becomes, in turn, provided with sexual organs. Meanwhile, the same conclusion has been reached with regard to many other parasitic worms, inhabiting insects and other of the lower animals.

In this way it became evident that none of the animals formerly supposed to be spontaneously generated were really produced in that manner. The evidence could not be resisted that, however obscure the origin of a species might be, a complete study of its natural history would always establish the fact that its reproduction took place, exactly as in other instances, by means of fertile eggs; and that its different generations would thus be connected with each other by the unbroken succession of parents and progeny. The adoption of this view was general and almost universal. In 1828 Cuvier had already published an edition of Pliny's Natural History, with commentaries of his own; and, in alluding to the author's statement, that some kinds of shell-fish are produced in sandy deposits "by the spontaneous operation of Nature," he says, in a foot-note:[2]

"It is altogether untrue that animals are ever formed by spontaneous production. We are now perfectly acquainted with the eggs of these shell-fish and their whole mode of generation. The Aphya (the fish thought by the ancients to originate from the foam of the sea) is simply the young fry of larger fish; and so of all the rest."

[1] Untersuchungen über Trichina Spiralis. Leipzig, 1860.

[2] Pliny, Historia Naturalis. Paris, 1828. IX., lxxiv.

With this conclusion we may regard the second period in the history of spontaneous generation as brought to a close. Cuvier evidently regarded the question as settled; and, in fact, it was so and still is, for all classes of animals which were known to the earlier naturalists.

But every extension of our knowledge in the natural sciences, not only adds to the information already possessed, but often brings into view, in addition, a new outlying territory in which every thing is at first doubtful and undefined. This is what happened in the present instance. For while the microscope was enabling experimenters to settle the question of spontaneous generation for all known species of animals, it discovered at the same time an entirely new and very extensive class of living beings, which had never before been known to exist. As early as 1675, Leeuwenhoek discovered in the rain-water which ran from the roof of his house, or was caught in open vases, a number of little organisms, too small to be distinguished by the unaided eye. On account of their minute size and animal organization he called them "animalcules." But they were soon found to make their appearance with astonishing rapidity in all watery infusions of decaying organic matter exposed to the air; and from this circumstance they received, some time afterward, the name of *Infusoria.*

As the construction and powers of the microscope improved with time, and a larger number of observers employed it in the investigations of natural history, these little bodies became the objects of great interest. Many different species were discovered, and their structure and habits fully described. In 1838 Ehrenberg published a magnificent work, with elaborate colored plates, entirely devoted to them, in which he described more than seven hundred different kinds. Two circumstances, relating to the infusoria, especially attracted the interest of observers, namely: 1. The fact that they constituted an entire class of living beings, previously invisible and unknown; and 2. The rapidity of their production and the immense numbers in which they exist.

In the opening chapters of his book,[1] Ehrenberg speaks of them as follows:

[1] Die Infusionsthierchen, als vollkommene Organismen. Leipzig, 1838.

"In the clearest waters, and also in the turbid, acid, or saline fluids of the most varied localities, in springs, rivers, lakes, and seas, often even in the internal parts of living plants and animals, not excepting the human body—and in all likelihood periodically mingled with the dust and watery vapor of the entire atmosphere—there exists, unperceived by the ordinary senses, a world of minute living organisms which have now for seventy years borne the name of infusoria. In the bustle of every-day life, this mysterious and immeasurable kingdom of living animalcules is passed over without interest or recognition. But for the quiet observer, who brings them under closer examination by the aid of magnifying instruments, they surpass all anticipation in the singularity and magnitude of their relations. In any single drop of standing dusty water, or solution of decaying material, we can frequently distinguish by the microscope actively-moving bodies, from $\frac{1}{1200}$ to less than $\frac{1}{20000}$ of an inch in diameter, often so crowded together that the spaces between them are hardly equal in size to their own bodies; and we can readily estimate, without exaggeration, that such a drop is inhabited by from one hundred thousand to many millions of these animalcules."

These microscopic infusoria, owing to their incalculable numbers, may even tinge extensive collections of water with well-marked colors. Ehrenberg has seen pools and ditches in the neighborhood of Berlin colored from this cause of a brick-red, and afterward of a blood-red hue. To some of them the property has been attributed of generating light; so that, although individually too small to be visible, they may produce an extensive phosphorescence on the surface of the sea. Some of the forms, originally included among the infusoria, are provided with calcareous or siliceous coverings; and when they die, these minute shells form by their agglomeration, mingled with other earthy matters, the substance of various rocks and soils. A deposit of mud has been found near the shores of Victoria Land, within the Antarctic circle,[1] chiefly composed of the siliceous shells of Diatomaceæ, which is of unknown thickness, but extending no less than four hundred miles in

[1] Carpenter on the Microscope, p. 302. Philadelphia, 1856.

length by one hundred and twenty miles in breadth. Ehrenberg regarded these creatures as forming, as a class, "by far the greatest number and perhaps also the largest mass of living animal organisms on the surface of the globe."

The infusoria exhibit among themselves a great diversity of form, size, and organization. Some of them, like *Vibrio*, *Monas*, *Spirillum*, and *Bacterium*, are either of the simplest possible organization, or else are too minute to allow their structure to be distinctly visible. They are from $\frac{1}{8000}$ to $\frac{1}{600}$ of an inch in length, and in thickness often not more than $\frac{1}{18000}$ of an inch. They are, however, in active motion, in a straight, spiral, wriggling or zigzag direction, notwithstanding that in most of them no visible organs or means of locomotion exist. Others, like *Chlamydodon*, *Ervilia*, *Paramecium*, *Kerona*, etc., from $\frac{1}{750}$ to $\frac{1}{125}$ of an inch in diameter, are covered on various parts of their surface with vibratile cilia, by which they move with repidity through the water. Others, like *Vorticella*, are attached by a slender contractile stem to some solid body beneath the surface, and have an oblique ring or crown of moving cilia upon the wide extremity of their bodies.

These animalcules are of especial interest in connection with the subject of spontaneous generation; for, by common consent, the question is now narrowed to the class of infusoria alone. No one at the present day imagines any of the higher animals to be produced spontaneously. It is only the infusoria in regard to which the doubt still exists.

For some years after the first discovery of the infusoria, a variety of fanciful characters were attributed to them which they did not in reality possess. The whole subject was so new and the field of observation so extensive, that some of the opinions adopted as to their physiology and organization were due simply to inaccurate or incomplete observation. The following notions, for instance, were occasionally entertained in regard to them:

1. They were thought to have no regular or determinate anatomical form; but to have resulted, as it was said, "from the capricious and wanton exercise of the organic powers of Nature."

2. They were thought to exhibit an indefinite or proteiform changeability of external configuration.

3. It was imagined by some that there was a frequent or even constant transition or reciprocal metamorphosis of the various infusorial forms into each other.

Ehrenberg, however, demonstrated that these ideas were erroneous. He showed that the infusoria have a regular and definite form, and that they may be classified like other animals, in genera and species; that they are not transformed into each other, but that they have a distinct organization, which is always the same for each particular species. At the time when he published his great work on the infusoria, he had already decided against their appearance by spontaneous generation; but, before that period, the question had been discussed with considerable vivacity by two eminent observers of the last century, namely, Needham and Spallanzani.

Needham was an English priest and naturalist, born in London, in the early part of the eighteenth century. He was educated at the Catholic College of Cambray, in France, where he afterward took holy orders. He was occupied for the greater part of his life in teaching, either as professor or private tutor, and was finally appointed Director of the Academy of Maria Theresa, at Brussels. He wrote on microscopic animalcules, on polypes, on the barometric measurement of heights, and made researches on various questions of physics and natural history. In 1748 he originated the idea that the infusoria were produced by a kind of reorganization of decaying organic materials. At that time this particular theory had been abandoned for all other animals and plants, and had not yet been connected with the newly-discovered class of infusoria. This is evident from Needham's own language in the opening sentences of his first paper[1] on the subject:

"Modern naturalists," he says, "have unanimously agreed to lay down for a certain Truth, that every plant proceeds from its specific Seed, and every animal from an Egg, or something analogous, preëxistent in a Parent of the same kind."

Needham, however, believed that he had seen infusoria produced under circumstances where no eggs or germs could have

[1] Philosophical Transactions, xlv., 615.

preëxisted in the solutions. In order to provide for this, he took the juices of meat which had been extracted at a high temperature, and enclosed them, "hot from the fire," in glass phials, together with air also previously heated, and shut off from communication with the atmosphere by tightly-fitting corks. He found that in these infusions, after a few days, animalcules made their appearance; and as all living eggs or germs previously contained therein must have been destroyed by the heat, and no new ones could have been introduced through the closed necks of the bottles, he concluded that they had been generated from the dead and decomposing material by a kind of "vegetative force" residing in the solutions.

This opinion, on the other hand, was opposed by Spallanzani.

Spallanzani was an Italian naturalist, Professor of Natural History in the University of Pavia. He was a man of great acquirements, an honorary member of nearly all the academies of Europe, and universally held in the highest estimation. He wrote much and made many original and important investigations on the physiology of the lower animals, their respiration, digestion, the reproduction of lost parts, generation, the preëxistence of eggs and germs, and especially on the structure and characters of the infusoria. He thought that Needham's experiments were wanting in precision, from the fact that the degree of heat employed was not accurately determined, and the mouths of the phials not sufficiently protected from the external air.

He therefore devised and executed certain experiments in which the heat applied should be fully destructive to all preëxisting germs, and in which also the access of new germs from without should be effectually prevented.

For this purpose he took glass flasks containing air and organic infusions, and sealed them hermetically by melting together the sides of their narrow necks. He then kept these flasks immersed in boiling water for the space of an hour, and afterward exposed them to ordinary temperatures, such as were favorable to the generation of infusoria. The result of these experiments was that, "when the flasks were afterward opened, not one of them showed the least appearance of ani-

malcules." It is a curious incident to find Spallanzani thus doing for the infusoria, in 1775, almost exactly what Redi had done for maggots and insects a little more than a hundred years before. I have given the account of these experiments with some detail, because they were the first in which the question was tested with so much rigor and exactitude. Spallanzani's conclusion was evidently this: that when the living germs already existing in the solution had been killed by boiling for an hour, and the access of others from without was absolutely prevented by hermetically sealing the flasks, there was no production of life within, and consequently no spontaneous generation.

But Needham was not satisfied with these results. He objected that so prolonged a boiling would not only kill the living germs, but that it would also impair, and perhaps destroy, the "vegetative force" of the infusion itself; and that this was the reason why animal life was not afterward developed in it.

This objection was a perfectly reasonable one. An organic solution which has been boiled is no longer in the same condition as before; and it was by no means certain whether the "vegetative force" supposed to exist in it, by which it was capable of generating animal life, might not be injured or destroyed by such a process. If so, how could the question be settled? How could the infusion be prepared in such a way as to destroy all its living germs, and yet not to interfere with its power of producing animal life?

Spallanzani undertook to surmount this difficulty; and he did so by a series of exceedingly careful and well-arranged experiments.

He first took a number of vegetable and animal infusions, which, as experience had shown, would inevitably become inhabited by infusoria, if exposed to the air at ordinary temperatures. He boiled these infusions for periods varying from half an hour to two hours, and afterward kept them in loosely-stoppered bottles, at ordinary temperatures. At the end of eight days they all contained infusoria; those which had been boiled for two hours as abundantly as those boiled for a shorter time. This showed that the previous ebullition had

not, in point of fact, destroyed the vegetative force of the liquid; and that, if the infusoria were really produced by spontaneous generation, they would appear in a boiled infusion as readily as in one which had not been subjected to that process.

He then proceeded to experiment with similar fluids, boiled as before, but protected from communication with the external atmosphere. He took thirty-six flasks, containing nine different infusions, together with a full supply of atmospheric air, sealed them hermetically, and immersed them in boiling water for periods varying from half a minute to three-quarters of an hour. He then kept them under observation, in company with other flasks containing similar infusions but exposed to the air. At the end of eleven days, when the open flasks had become filled with animalcules, he opened and examined those which had been hermetically sealed. The result was, that boiling for even two minutes, in closed vessels, prevented the appearance of all animalcules of larger size and higher organization; while boiling for three-quarters of an hour prevented the appearance of all infusoria whatever, even those of the lowest order and most minute size. His conclusion was evident, as expressed in the following words:[1]

"We are, therefore," he says, "induced to believe that some of the germs included in the infusions may resist the action of heat for a certain time, but at last all are destroyed by it. And we may accordingly conclude that the crowds of animalcules which show themselves in open vessels, in organic infusions which have already been subjected to great heat, are not produced there because their germs have resisted this temperature, or because they have been generated spontaneously; but because new germs have been introduced into the infusion from the atmosphere after the boiling has ceased."

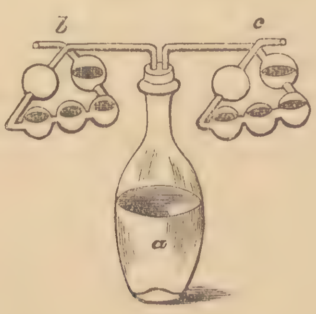
These experiments of Spallanzani carried conviction generally to the minds of naturalists at the time; especially as the discoveries in regard to the mammalian egg and its development were all tending in the same direction. Only one point remained which still seemed to admit of a doubt. This was,

Opuscoli de Fisica animale e vegetabile, vol. i., p. 12. Modena, 1776.

that the experiments in question had been carried on in sealed vessels. These vessels, it is true, contained air, a substance necessary to the maintenance of all animal life; but the air was confined within a limited space. Might it not be that the production of infusoria required a *renewal* of air in the interior of the flasks, or that there should be a kind of ventilation going on during the course of the experiment? How to provide for this, and yet prevent the air, daily introduced into the flask, from bringing with it living germs, was now the object to be accomplished.

It was done in 1836 and 1837 by Franz Schultze and Theodor Schwann, in Germany, by two different methods:

Schultze took a glass flask, half filled with an infusion of various animal and vegetable matters, and which had been boiled for a long time on the sand-bath. The neck of the flask was fitted with an air-tight stopper; and through the neck of this stopper there projected two narrow glass tubes, bent at right angles, through which the renovation of the air was to take place. When the whole was thoroughly heated to the boiling-point, and all the air in the flask expelled, and steam passing out freely through the tubes, the end of each



(*a*) Flask containing the organic infusion.
(*b*) Bulbs containing sulphuric acid.
(*c*) Bulbs containing solution of caustic potassa.

tube was attached to a series of bulbs, containing on one side sulphuric acid, and on the other a strong solution of caustic potassa. All the air, accordingly, which entered the apparatus must pass through these liquids; and though the air itself would not be decomposed or injured by the passage, it would

be purified from all living germs which might be present in it.

The flask was then placed at a window, exposed to the light and warmth of the summer weather, and air was drawn several times daily through the apparatus, entering through the sulphuric acid, and passing out through the potash. The result was as follows:[1]

"From the 28th of May to the beginning of August the experiment continued, with daily renewal of air, without the edges of the fluid, examined every day by the microscope, showing any living animal or vegetable forms. And when, at last, the apparatus was taken apart, there was no trace either of infusoria, or confervæ, or fungi, to be found in the whole fluid. On the other hand, all three showed themselves in great abundance after the flask had remained for a few days open to the atmosphere."

Schwann's experiment was similar to this, except that the air entering the apparatus was purified, not by sulphuric acid, but by passing through three inches of a narrow glass tube heated to over 600° F. It was thus calcined, and its living germs destroyed. The experiments lasted several weeks, and the liquid showed no sign of infusoria.[2]

Thus it was shown, beyond a reasonable doubt, that the infusoria were produced, as a general rule, not by spontaneous generation, but from their eggs or germs floating in the atmosphere. It is true, no one had ever seen these germs. They had never been recognized, even by the microscope; and their mode of origin and their development were both entirely unknown. Still they might readily exist in the atmosphere and yet escape observation. The animalcules themselves are so minute as to be invisible to the naked eye; and their germs, if any such exist, must be smaller and lighter still. Ehrenberg himself expressed this view in the following words:[3]

"Insignificant as is the weight of such invisible animalcules, yet it is calculable and has been estimated; and it is certain that the lightest current of air, which is capable of lift-

[1] Poggendorf's Annalen, 1836, xxxix., p. 487.

[2] Ibidem, 1837, xli., p. 184. [3] Die Infusionsthierchen, etc.

ing a feather, might play with these little bodies like so much vapor."

The atmosphere, in fact, as ordinary experience shows, is abundantly capable of wafting about, often to great distances, bodies much larger and more weighty than the infusoria or their germs. The phenomenon known as "sulphur-rain" is an instance of this. In the spring or early summer, after a heavy shower, the edges of standing pools are sometimes seen to be fringed with a fine yellow powder, bearing a very striking resemblance to flowers of sulphur. Microscopic examination shows this deposit to be nothing else than the yellow pollen of the blossoms of the pine. The pollen, at the time of its maturity, is scattered from the trees, and floats imperceptibly in the atmosphere, until the rain brings it down and it becomes visible on the surface of standing water. We know, too, that in point of fact, the atmosphere is everywhere pervaded by minute dust-like particles, which subside very slowly and are easily dispersed by the slightest current. These particles are usually imperceptible, on account of their minuteness and transparency, and the greater reflection of light by other surrounding objects. But if a single beam of sunlight be admitted through a narrow opening into a darkened chamber, the floating particles will at once become visible against the dark background, and can be plainly seen moving up and down in the track of the sunbeam.

In this way the scientific world gradually admitted the idea, which afterward met with general acceptance, that the air always contains an abundance of infusorial germs, carried hither and thither by the atmospheric currents, and ready to be developed into living animalcules whenever caught by the surface of standing water, or introduced into an infusion suitable for their nourishment. This conclusion was unavoidable: since it had been shown that, in boiled infusions exposed to the atmosphere, animalcules were always produced; while none made their appearance if all introduction of germs from without were rigidly excluded. Accordingly, it was generally conceded, during the earlier part of the present century, that the question of spontaneous generation was settled. Ehren-

berg in 1838, Milne Edwards,[1] Longet,[2] Bergmann and Leuckart,[3] Robin,[4] Valentin,[5] Owen,[6] Carpenter,[7] all took the same view. The production of living beings without parents was a theory admitted to have no reasonable basis for its support, and was regarded simply as a curious relic of antiquity.

We have now reached the end of what may be called the third epoch in the doctrine of spontaneous generation. The first period was that in which it was regarded by the ancients as the regular and normal mode of production for a large class of animals. The second period was that from Redi to Cuvier, when it was narrowed down to a rare and exceptional mode of production for a few only of the most obscure species, and finally shown to be untenable even for them; while the third was that which opened with the discovery of the infusoria, and the experiments of Spallanzani and others on these animalcules. In the case of infusoria, however, the evidence was also found to be against the idea of their spontaneous generation, and by the year 1850 the discussion was regarded as closed.

But in 1858 it began again.

This time it was in France that the question was reopened. M. F.-A. Pouchet—corresponding member of the Institute, Professor of Zoology in the Natural History Museum of Rouen, a naturalist who had won distinction in the scientific world by his works on the anatomy and physiology of invertebrate animals, on ovulation and fecundation, on the infusoria, etc., and who was remarkable for the clearness and vigor of his style, and for his restless zeal and scientific activity—took up the subject afresh. He maintained that spontaneous generation was possible in the case of the infusoria, and that it had indeed succeeded in his hands. He was followed by several other observers who took a similar view, and for several years the de-

[1] Leçons sur la Physiologie, etc. Paris, 1857.

[2] Traité de Physiologie. Paris, 1850–1861.

[3] Vergleichende Anatomie und Physiologie. Stuttgart, 1852.

[4] Végétaux Parasites. Paris, 1853.

[5] Physiologie. Braunschweig, 1847.

[6] Comparative Anatomy and Physiology of the Invertebrates. London, 1843.

[7] General and Comparative Physiology. London, 1851.

bate on this question became, if possible, more animated than before.

The motive for this last renewal of the discussion, however, was somewhat different from any of those which had preceded it. Since the beginning of the century the science of geology had been gradually acquiring its present form, and had been particularly extended by the discovery of fossil remains of animals different from those which are now in existence. It was also found that the earliest remains of animal forms, thus discovered, belonged to the lower orders; reptiles and fish, for example, having apparently been fossilized before birds or quadrupeds, and the invertebrate animals generally before the vertebrata. The idea thus originated that animal life upon the globe had consisted in a series of different forms, following each other in a certain order of succession; the simpler forms appearing first, and those which were more highly organized coming afterward. This very naturally led to the theory that the higher forms of organization, man included, instead of being created independently by themselves, had been gradually developed during the course of ages, out of the inferior types. Furthermore, as some of the deepest strata showed no organic remains whatever, it was thence assumed that a time had existed in the history of the earth when even these lower forms of life had not yet made their appearance. In this way the conclusion was reached that the lowest and simplest of living beings, the earliest to make their appearance upon the earth, had been first formed by the spontaneous organization of inanimate materials; and that they had afterward produced, by a continuous process of gradual development, the whole series of animal life which finally peopled the surface of the globe.

These conclusions may not all have been strictly deducible from the known facts of geology; but they were very widely adopted, and no doubt gave a new stimulus to the idea of spontaneous generation. This is evident from the expressions used by Pouchet himself. "For all reflecting minds," he says,[1] "heterogeneous production is a logical consequence of the appearance and ascending development of organized beings upon

[1] Pennetier, Origine de la Vie, Paris, 1868; preface by M. Pouchet.

the globe." The most recent discussion of the question, therefore, though essentially the same as before, was yet carried on, to some extent, from a different point of view.

Some years previously a book had appeared in England which excited considerable attention, entitled "Vestiges of the Natural History of Creation;" and, in a sequel to this work, published in 1845, reference was made to certain curious experiments by a Mr. Crosse and a Mr. Weekes. These two observers claimed to have produced a new species of acarus by means of a continuous current of electricity passed for a long time through a saline solution. The experiments of Mr. Crosse were the first, and the new creature thus produced received the name of the *Acarus Crossii*. Mr. Weekes's experiments were given in detail in the sequel just mentioned. He prepared a close glass jar containing ten ounces of a solution of ferrocyanide of potassium, supplied with an atmosphere of pure oxygen, and traversed by a constant current of electricity from a galvanic battery of ten pairs. The experiment began on the 26th of May, 1842. Five months afterward a number of nearly full-grown acari were discovered on the sides of an open jar containing the same solution and also traversed by the electrical current. Afterward they appeared also in the close jar, as indicated by Mr. Weekes's description.

"In the beginning of June, 1844," he says, "rather more than two years from the commencement of these operations, in examining with a lens the deposit of oxide of iron on the bottom of the jar, I saw for the first time unequivocal proof of the existence of animal life within the close vessel. Several spinous processes of the acari and other remains were detected floating on the surface of the solution, and others attached to the surface of the glass a few lines above the liquid; while, under circumstances somewhat more obscure, several entire dead insects were perceived amid the flakes resting on the bottom of the jar."

An almost ludicrous circumstance was noticed at this point in the experiment; namely, that no mechanical provision had been made for the preservation of the living insects generated from the solution, so that, as Mr. Crosse remarked on visiting the apparatus, they would fall in and be drowned as fast as they were produced.

"This conjecture was right," the experimenter goes on to say, "for, although I have latterly watched the proceeding with diurnal care, I have never identified the presence of more than two living insects at a time within the close apparatus, and these as speedily and invariably shared the fate of their predecessors." Thus the electrified liquid, which was supposed to have given origin to living insects, proved immediately fatal to them as soon as they were produced.

These experiments were received with almost universal incredulity. The high grade of organization of the acari, a class nearly related to insects, and the fact that those appearing about the solution in open vessels soon began to lay eggs and reproduce their kind, did not invite general confidence in the idea of their spontaneous generation. Mr. Crosse sent to the French Academy of Sciences a communication describing his experiments, accompanied by a phial containing a specimen of the acarus preserved in spirit;[1] but it did not obtain from the Academy an encouraging reception. The truth is, that in such an experiment it is a capital and indispensable condition of accuracy that no possible communication should exist between the interior of the apparatus and the external atmosphere. Wherever joinings are made between its different parts they are apt to become imperfect; and the smallest crevice will, if the experiment be long continued, give rise to currents of air passing outward and inward, which may bring with them organic germs, and thus vitiate the results. This is owing to the inevitable fluctuations of temperature. For when the external atmosphere is rarefied by heat, an outward current from the jar is at once established; and when it falls again, a corresponding inward current takes place, until an equilibrium is restored between the exterior and the interior. In the celebrated experiments of the acari, it did not appear that sufficient care had been taken to avoid this source of error so familiar to other observers.

The observations of M. Pouchet, however, in 1858, commanded more attention. He insisted that he had repeated the experiments of Schultze "with every exactitude," but

[1] Comptes rendus, October 30, 1837.

with different results. He also announced the production of a fungoid vegetation (Aspergillus), from a boiled infusion of hay enclosed in an atmosphere of oxygen over mercury. His plant, like the acarus of Crosse, was said to belong to an unknown species, and the experimenter consented to adopt for it the name of *Aspergillus Pouchetii.*[1] Other similar cryptogamous plants, protozoa and infusoria, were said to have been produced in similar boiled infusions, strictly protected from external contamination.

These communications excited immediate opposition. Milne-Edwards, Payen, Quatrefages, Claude Bernard, and Dumas, all reported contrary results. It was also objected that a heat of 212° Fahr. is not always sufficient to destroy the germs of cryptogamous plants, which will sometimes resist a much higher temperature. In some experiments, accordingly, a preliminary boiling may not have been sufficient to kill all the germs contained in the closed vessels, and this accounted for the subsequent appearance of organic life. Both Milne-Edwards and Claude Bernard, however, had found in their experiments that organic infusions, thoroughly boiled, and protected from all access of external air, did not produce any living infusoria.

M. Pouchet, who, together with his intellectual agility, seems to have appreciated also the humorous side of a discussion, turned upon his opponents with an unexpected reply. "The instant you assume," he says,[2] "that a temperature of 212° is not sufficient to destroy eggs and spores, the conclusions that have been accepted for the last twenty years, from the experiments of Schultze and Schwann, become absolutely null and void. And if, for such a reason, you condemn my own experiments as invalid, the same verdict must be pronounced on those of MM. Milne-Edwards and Claude Bernard; in which case it appears very extraordinary that no infusorial plants or animalcules appeared in the experiments of the four *savants* whose names I have quoted. This leads us, you perceive, to a consequence of extreme gravity; for if that be so, every thing is to be begun over again."

[1] Comptes rendus, December 20, 1858. [2] Ibidem, January 17, 1859.

The weight of the discussion, however, soon turned upon the supposed source of infusorial organisms; namely, the general dissemination of germs in the atmosphere.

M. Pouchet denied that the atmosphere contained these germs in any abundance. He contrived an apparatus called an "aëroscope," for collecting upon a glass plate the dust-like particles of the atmosphere; and, in thirty-five cubic inches of air collected in his laboratory by this means, he "did not discover a single infusorial egg or a single spore." He collected the atmospheric *débris* from freshly-fallen snow; and in several hundred observations he found "only two encysted infusoria or eggs, two dead and deformed infusoria, three naviculæ, three bacillariæ, and two bacteria; nothing else which could be referred to either animal eggs, or spores."

He maintained, therefore that the atmosphere was in reality very poor in germs, and altogether incapable of accounting by such means for the abundant production of infusoria in organic infusions.

This part of the question was taken up by M. Pasteur, a chemist of eminence, whose attention had already been especially directed to the subject of fermentation. His experiments were intended to determine whether or no the atmosphere, in coming in contact with an organic solution, brought with it, beside its own constituent gases, any thing capable of producing living organisms. In this inquiry, the enterprise and untiring industry, exhibited by the experimenters on both sides, form one of the most remarkable chapters in the history of spontaneous generation. There is evidence that some feeling was excited in the course of the debate, and the discussion may almost be said to have kept the Academy in a turmoil for some six or seven years.

M. Pasteur took glass flasks, filled to about one-third of their capacity with a clear watery infusion of brewer's yeast. He then raised the liquid to the boiling-point; and while ebullition was actively going on, drew out the necks of the flasks to a narrow point, and sealed them in the flame of the blow-pipe. He thus had the boiled fermentible liquid, after cooling, enclosed in an air-tight vessel, with only its own rarefied vapor. He could then, by cutting off the neck of the

flask in any particular locality, allow it to be refilled with the external atmosphere, which would pass in to occupy the vacant space; and, the flasks being immediately resealed, the effect of this atmosphere upon the liquid could be observed.

He prepared sixty of these flasks. Twenty of them were afterward opened and resealed in the country, at a distance from any habitations, at the foot of the heights which form the first plateau of the Jura range, thus exposing the liquid to the air of that locality alone. Twenty others were opened and resealed on one of the Jura mountains, twenty-five hundred feet above the sea-level; and the remaining twenty on the Montanvert, in the valley of Chamouni, near the "Mer de Glace" glacier, at an altitude of six thousand feet.[1] Now, the chemical constitution of the air from these different localities must have been the same; and, if the production of infusoria depended simply on its chemical influence, they should be generated indifferently in all the flasks used for experiment. On the other hand, if the atmosphere contained floating organic germs, these might easily be more abundant at the lower levels, and less so in proportion to the altitude attained.

The result was that, of the first twenty flasks, filled and resealed at the foot of the Jura, eight afterward produced living organisms; of those filled on the flanks of the mountain, at twenty-five hundred feet elevation, five flasks showed similar productions; and of those filled with air on the Montanvert, at six thousand feet, only a single one became the seat of organic life.

Pouchet, however, performed similar experiments with different results. In company with MM. Joly and Musset, of Toulouse, he took flasks containing infusions of boiled hay, and filled them with air, in the manner above described, at two different localities in the Pyrenees. Two were thus opened and resealed at La Rencluse, at six thousand two hundred and fifty feet elevation, and two others on the Maladetta glacier, at a considerably higher level. M. Pouchet even took pains to ensconce himself in a crevasse of the glacier, and with his back resting against one wall of ice

[1] Comptes rendus, November 5, 1860.

and his face fronting another, filled his flasks with the air of this unusual locality.[1] Nevertheless, in the course of a few days the infusions, after being kept at a warm temperature, contained infusorial organisms, such as Bacterium, Monas, and Spirillum, "in prodigious quantity."

He also took pains to procure flasks of air from the summits of the Buet, Monte Rosa, and Mont Blanc, altitudes varying from ten thousand to more than fifteen thousand feet; and these specimens of air, brought to Rouen, and added to boiled organic infusions, all produced infusoria.

Now, it would seem that, if any air could be regarded as absolutely pure, it would be that which had been taken from these localities. And yet M. Pouchet himself, in the course of his indefatigable researches, met with a singular proof that light bodies may be transported by the atmosphere even to the tops of the highest mountains. A phial of pure, newly-fallen snow was taken[2] by Dr. Kolbe from the summit of Mont Blanc, and brought to Pouchet. On melting, it made about one cubic inch of water, which was, to all appearance, pure and clear. But a slight deposit was formed in it on standing, and this deposit contained the following substances: a few corpuscles of a mineral nature, a dozen young cells of Protococcus nivalis, two woollen filaments, one white and one blue, a fragment of a confervoid plant, and a minute tuft of vegetable air-tubes. Whoever has experienced the occasional force of the wind on Alpine summits, will not be surprised at this result.

M. Pouchet, however, declared that all his examinations showed the atmosphere to be everywhere poor in organic germs, and often entirely destitute of them; and that its capacity for generating animal life resided, not in these germs, but in the general vivifying power of the air. M. Pasteur, on the other hand, insisted that, the chemical constitution of the air remaining the same, its power of producing organic life varied with the locality from which it was taken; and this because the number of germs contained in it varied in different places.

[1] Comptes rendus, September 21, 1863. [2] Ibidem, 1864, liv., p. 189.

Both the disputants stated their positions in definite terms.[1]

M. Pouchet said: "I assert that, from whatever region of the globe I take a quantity of atmospheric air, if this air be placed in contact with a putrescible liquid in hermetically-sealed vessels, the liquid will invariably become filled with living organisms."

M. Pasteur said: "It is always possible to obtain, in a particular locality, a notable volume of atmospheric air which, without having been subjected to any physical or chemical modification, is nevertheless incapable of exciting any change whatever in a putrescible liquid."

These assertions, emanating from two eminent observers, both members of the Academy, were so diametrically opposed to each other, that it was agreed to refer them to a committee in whose presence the requisite experiments should be performed, and who should report to the Academy on the result. Such a committee, composed of five members, was accordingly formed, and entered upon its labors in June, 1864, in the Chemical Laboratory of the Museum of Natural History, at the Garden of Plants.

M. Pasteur first presented three of his flasks which had been filled with air, four years previously, on the Moutanvert, and had remained ever since perfectly unchanged. One of them was opened under mercury; and the air which it contained, on being analyzed, was found to have the natural constitution of the atmosphere (twenty-one parts of oxygen to seventy-nine parts of nitrogen). Another flask was opened by a minute orifice at the neck; and, after being left for three days exposed to the atmosphere, it contained flakes of a cryptogamic vegetable growth, which subsequently became largely developed.

M. Pasteur then prepared and sealed, before the committee, sixty flasks, similar to those previously used. Nineteen of them, after cooling, were opened and immediately resealed in the amphitheatre of the Museum; nineteen on the top of the dome of the same building; and eighteen others at a country-house, a few miles from Paris, under a thick growth of poplars. Afterward, microscopic vegetations were devel-

[1] Comptes rendus, February 20, 1865.

oped in five flasks of the first set, six of the second, and sixteen of the third. All the remainder were unchanged at the end of over four months.

The committee subsequently reported [1] the result of their experiments, and gave as a conclusion that *the facts observed by M. Pasteur, and contested by M. Pouchet, were of the most absolute exactitude.*

It thus seems to have been placed beyond a doubt that the atmosphere is incapable, from its chemical constitution alone, of exciting organic growth in a boiled infusion; but that it often introduces with it into the solution invisible germs which do have this effect, the proportion in which these germs are present varying with the locality from which the air is derived.

But up to this time the dispersion of organic germs in the atmosphere was not an actually observed fact; but only a probable inference from the results of experiments like the above. This is what gave a certain weight to the objection of M. Pouchet, when he said in one of his communications: [2] "It seems to me that, when an experimenter declares that he can collect from the atmosphere either the eggs or spores of microscopic organisms, we have a right to demand that he should show them to us."

No one, in fact, had succeeded in collecting these germs from the air in any abundance, in such a form as to be visible and recognized.

This, however, was accomplished by Dr. Lemaire in 1864.[3] He adopted the plan of condensing the vapors of the atmosphere in glass tubes by means of artificial cold. The moisture thus obtained was then kept in the tubes, well stoppered, together with an equal or double volume of air, at a temperature of from 73° to 86° Fahr. The collections were made in the month of July, from a marshy neighborhood in the country, from the Garden of Plants in Paris, and from a village near the city, situated at two or three hundred feet higher elevation. The liquid, when first condensed, was colorless and

[1] Comptes rendus, February 20, 1865. [2] Ibidem, March, 12, 1860.
[3] Ibidem, August 17, 1864.

limpid. It contained microscopic vegetable germs or *spores ;* a great number of *pale cells*, of different dimensions; a considerable abundance of very *small semi-transparent bodies* (thought to be the germs of future infusoria) of a spherical, ovoid, or cylindrical shape, sometimes regular and sometimes irregular; certain *brownish corpuscles*, apparently of vegetable origin; *starch-grains ; dust-particles*, and *cubical crystals*. Within twenty-four hours afterward there were developed an abundance of living infusoria, bacteria, vibrios, spirilla, and monads, together with ramified cryptogamic vegetations. Exactly in proportion as the cryptogamic vegetations and the infusoria were developed, the spores and the small semi-transparent corpuscles were found to disappear.

Thus the actual existence of organic germs in the atmosphere was demonstrated; and there could no longer be any doubt that these germs, when introduced into an organic infusion, are abundantly sufficient to account for the production of infusorial and vegetative life.

For we know that these low forms of organization are especially distinguished by their power of rapid multiplication Each individual plant of *Reticularia maxima*,[1] a species of fungoid vegetable, produces no less than ten millions of spores; and, according to Dr. Carpenter,[2] a large kind of fungus, the *Bovista giganteum*, has been known to grow so rapidly that its cells must have been produced at the rate of four thousand millions per hour. Many of the infusoria also multiply themselves by division, and in this way increase rapidly in numbers in any infusion which is suitable for their growth. Prof. Bastian[3] has seen under the microscope a bacterium, of moderate size, "divide into two, and each of these into two others, somewhat smaller, in the course of fifteen minutes." But if such an organism were only to divide into two once in every fifteen minutes, and if this process were to go on for six hours, we should have at the end of that time over sixteen millions of bacteria, produced from a single individual. There is no

[1] Quoted in Longet, Traité de Physiologie, vol. ii., part iii., p. 13.

[2] General and Comparative Physiology, p. 95.

[3] Origin of the Lowest Organisms, p. 6. London, 1871.

difficulty, therefore, in accounting for the abundance in which the infusoria may appear in a solution, after a few germs have once been introduced from the atmosphere.

And yet the question is not fully settled. Even supposing that the animalcules which appear in organic infusions come from atmospheric germs, and granting this to be their usual and regular mode of propagation, may they not also, in some instances, arise by spontaneous generation? May they not show themselves, as an exceptional circumstance, in liquids from which all access of the atmosphere has been excluded?

The only form of experiment calculated to give a direct answer to this question is that of organic solutions subjected to heat, and kept in glass vessels hermetically sealed. Here, there is no possibility of error. There are no joints which may be imperfectly secured, and no means of communication whatever with the external atmosphere. Consequently, when infusoria make their appearance in such a liquid, either they must have been produced spontaneously, or else their germs must have resisted the heat which has been applied beforehand.

Spallanzani, it will be remembered, found reason for believing this to be the case. A single boiling of the liquid in a closed flask prevented the appearance of all infusoria of the higher orders; but other and simpler forms continued to be developed even when the liquid had been boiled continuously for half an hour. It was only after boiling for three-quarters of an hour, that all infusorial life failed to appear in the solutions. Mantegazza,[1] in 1859, sealed up in a glass tube a decoction of lettuce, leaving two-thirds of the tube filled with air, and then exposed it for thirty minutes to a temperature of 212° Fahr., in one instance even for forty minutes to a temperature of 284°, and two or three days afterward found living infusoria in the liquid. Pasteur[2] found that milk boiled for two or three minutes in a flask, and then supplied with calcined air, became afterward filled with infusoria; but, if boiled four or five minutes, the production of infusoria diminished in proportion to the time of ebullition. On the other hand, if

[1] Comptes rendus, January 31, 1859. [2] Ibidem, May 7, 1860.

the milk were boiled at a temperature of 230° Fahr. ($1\frac{1}{2}$ atmospheres), it never yielded infusoria.

But altogether the most careful and complete of the modern experiments on this point are those of Prof. Jeffries Wyman,[1] of Harvard University. In fact, the two experimenters who have pursued this part of the investigation above all others, in a thoroughly careful and rigorous manner, are Spallanzani in 1776, and Wyman in 1867. Both of these observers found that infusoria are produced in organic solutions which have been subjected to boiling. But with Spallanzani, their production was limited to a boiling of half an hour in duration. Wyman, on the other hand, succeeded in obtaining them after an ebullition of four hours; although a longer boiling than this prevented their appearance altogether. "In pushing the experiments still further," he says, "we have not found that infusoria appeared in any instance if the boiling were prolonged to five or six hours. Several experiments, in which many flasks were used, were tried; but the result was uniformly the same. Thus, a limit to the development of infusoria in boiling water was reached."

What are we to believe from these facts?

One circumstance it is important to remember. Nearly all the experimenters on this subject have found that a single exposure to 212° Fahr., in closed flasks, prevents the appearance of many of the infusoria; and that, the longer the boiling is continued, the fewer the instances or the numbers in which they appear, until at last a point is reached beyond which they do not appear at all. This looks very much as if the animalcules originated from preëxisting germs, which can resist a short boiling, but are killed by it if long continued. Otherwise, if they are produced by spontaneous generation, why should they not appear in a liquid which has been boiled five hours, as well as in one which has been boiled for half that time? We cannot say that it is because the boiling has changed the composition of the liquid, and thus unfitted it for the production of infusorial life. Spallanzani investigated this point, and showed that the same boiled infusions which

[1] American Journal of Science and Arts, xliv., September, 1867.

failed to produce infusoria in close vessels, became abundantly filled with them on exposure to the air. In Schultze's experiment, the infusion which had continued for two months in the apparatus, and had been examined daily without showing infusoria, after being opened contained vibrios and monads on the second day. In one of Pasteur's flasks which had remained four years unaltered, vegetations made their appearance in three days after it was opened.

On the other hand, if the infusorial germs preëxisted in the solutions, they must have, in many cases, a power of withstanding heat, which appears altogether exceptional. For a certain time it was taken for granted that a temperature of boiling water would destroy the infusoria and their germs, because such a heat is fatal to all animals and eggs, so far as known. But this was plainly reasoning in a vicious circle. It was assumed that, as a temperature of 212° would destroy all animal and vegetable germs, it would necessarily have that effect on those of the infusoria. But the infusoria were precisely those upon which its effect had not been tested; and, until this should be ascertained, such a general assumption, applied to all germs without exception, was evidently unfounded.

The truth is, that the limits of temperature, within which life is possible, vary with different classes of animals, even among those of higher organization. A warmth of 100° Fahr., which is the natural and even necessary temperature for most birds and quadrupeds, is fatal to frogs and other cold-blooded species. Various animals and cryptogamous vegetables have been found[1] living in hot springs, at temperatures varying from 150° to 208°. Payen satisfied himself that the spores of *Oidium aurantiacum*, a cryptogamous growth sometimes occurring in bread, would support, even in the moist condition, a temperature of from 212° to 248°, without losing their power of germination.[2] They were entirely destroyed only at a temperature of 266° or 284°. M. Pouchet found, by his own observation,[3] that the seeds of a Brazilian *Marecago*, after

[1] Wyman, American Journal of Science and Arts, xliv., September, 1867.

[2] Substances alimentaires, p. 362. Paris, 1865.

[3] Comptes rendus, 1866, lxiii., p. 939.

being boiled continuously for four hours, were, in many instances, unchanged in appearance, and afterward, on being planted, germinated freely. On the other hand, Prof. E. Frankland[1] has recently found a small kind of *ice-flea* living, full of vigor and activity, beneath stones embedded in the surface of the Morteratsch glacier, where the temperature of the enclosed air never rises above the freezing-point.

It is by no means certain, therefore, that the germs of infusoria which appear in boiled solutions, may not have resisted the action of boiling water. It is true that Prof. Wyman has shown,[2] by a series of very thorough experiments, that vibrios and similar infusoria lose their power, both of motion and reproduction, after being boiled for from five to thirty minutes. Prof. Bastian has even given evidence to show[3] that bacteria and vibrios lose their reproductive properties by being exposed for ten minutes to a temperature of 140° or 167° Fahr. But it is only the infusorial germs, not the infusoria themselves, which are supposed to preëxist in the atmosphere or the solution; and they may very possibly withstand a temperature which would be fatal to the fully-developed organism. Unless we admit, therefore, that the infusoria in question are sometimes produced in sealed vessels by spontaneous generation, the germs of these minute bodies must possess the singular power of living and reproducing their kind after having been exposed continuously for four hours to the action of boiling water.

But what are the organisms in regard to which this doubt exists?

It is by no means the infusoria, as a class. On the contrary, since the time of Ehrenberg, important progress has been made in the study of these minute animalcules, and our ideas of their structure and classification have been greatly modified.

In the first place, the whole group of Rotatoria, including *Rotifer*, *Stephanoceros*, *Floscularia*, and many others, have been entirely removed from the class of Infusoria, and assigned to that of Worms. Their complexity of organization

[1] Nature, No. 100, p. 426. [2] *Loc. cit.*
[3] Origin of Lowest Organisms, p. 55.

showed this to be proper; and their mode of reproduction is sufficiently manifest from the fact that living embryos, in process of development, can be often seen in the interior of their bodies.

Secondly, the idea of spontaneous generation has been abandoned for all the Ciliated Infusoria, constituting, at least, nineteen-twentieths of the class, as now understood. This group includes such forms as *Paramecium*, *Colpoda*, *Chlamydodon*, *Ervilia*, *Stylonychia*, *Kerona*, *Oxytricha*, *Urostyla*, and *Vorticella*—all those, in fact, which are more or less completely covered with cilia, and which move by the regular vibration of these little appendages. Within the last ten years it has been established, beyond a doubt, that many, and probably all, of these infusoria reproduce their kind by means of eggs, regularly fertilized in the ordinary mode of sexual generation. Balbiani,[1] Stein,[2] Engelmann,[3] and Claparède and Lachmann,[4] the most recent and accomplished observers on the subject, all agree on this point. Balbiani and Stein together have observed the process of sexual generation in no less than forty-seven different genera and sixty-six different species of the ciliated infusoria. Their fertile eggs are, in many cases, abundantly visible; and the embryos produced from them, discharged from the body of the parent, become developed into similar organisms.

Furthermore, the ciliated infusoria are never produced in boiled solutions which have been hermetically sealed or otherwise protected from the access of atmospheric germs. It is always and only the minute and more lowly forms that show themselves under these circumstances. By the almost universal testimony of experimenters on both sides of the question, the only infusoria, in regard to whose mode of generation there remains at present any doubt, belong to the four genera, Vibrio, Spirillum, Bacterium, and Monas; and, of these, bacteria and vibrios are by far the most frequent, and appear with the greatest persistency, in boiled infusions.

[1] Journal de la Physiologie, Paris, January, 1861.

[2] Organismus der Infusionsthiere, Leipzig, 1859, 1867.

[3] Zeitschrift für Wissenschaftliche Zoologie, 1862, xi., p. 347.

[4] Études sur les Infusoires, etc., Genève, 1856, 1861.

Now, these are precisely the smallest and most obscure of living organisms. They stand upon the extreme limits of the microscopic world; and in most instances no internal structure can be distinguished in them, the microscope revealing nothing but their form and motions. They were cited by Ehrenberg thirty years ago as the objects which escaped all satisfactory examination, and he refers them to the same category with those of the heavenly bodies which are indistinct on account of their remoteness. "Our experience," he says, "shows the organic creation to be as unfathomable in its minuteness as the celestial universe is in its magnitude, since the powers of our optical instruments are necessarily confined within certain limits, which, however, are not the limits of Nature. A 'milky way' of the minutest organisms runs through the genera Monas, Vibrio, Bacterium, Bodo."[1]

Another fact of some interest is, that these genera, with one exception, are all now considered by common consent as belonging to the vegetable kingdom. With regard to Monas there is a doubt in this respect; but all the Vibrioniæ, including vibrios, bacteria, and spirilla, are now classed among vegetables,[2] and are regarded as incomplete and transitory forms in the development of certain aquatic fungi. These were also the organisms which were found by Dr. Lemaire to be most rapidly developed in the moisture condensed by him from atmospheric vapor. "In a single drop," he says, "we counted more than two hundred specimens of Bacterium termo."

Thus we find that now, as always, the idea of the spontaneous generation of living beings is confined to organisms of which we know the least. Exactly where our definite knowledge fails, owing either to the minute size or the imperfect organization of these bodies, there commences the obscurity which hangs around their origin. It is very justly said, in support of their spontaneous generation, that, if this mode of production exist at all, it is precisely in the case of the simplest and most imperfect organisms that we should expect it. We might imagine a bacterium or a monad to originate in this

[1] Ehrenberg's genus Bodo was afterward assigned to other genera in the family of Monads.

[2] First established by COHN, Acta Academiæ, etc., Bonn, 1854, xxiv., part i., p. 116.

way, but not an eagle or an elephant. On the other hand, it is alleged that the imperfect organization of these minute forms is only apparent, and depends on the imperfection in our means of observation. When our microscopes and other aids to investigation have been still further improved, we shall find, it is said, that the bacterium and the vibrio possess an organization of their own, not less essential and complete in its way than that which we now know belongs to the ciliated infusoria. There is every evidence that at least their regular and normal mode of production is from germs disseminated in the atmosphere; and they themselves, as we have already seen, are embryonic or transitional forms in the development of a distinct vegetable growth. They are consequently to be regarded as an integral part of the cryptogamic vegetable organizations; and, notwithstanding the apparent simplicity of their structure, they no doubt, like other plants and animals, have their definite place in the organic world.